R&D, Foreign Technology and Technical Efficiency in Developing Countries

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Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

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Abstract
This study investigates the relationship between firms' innovation activities and efficiency in manufacturing firms in developing countries. We examine whether innovation activities including internal research and development (R&D) and adoption of foreign technology have differential effects on technical efficiency. We hypothesize that the relation between internal R&D and technical efficiency is positive; the relation between adoption of foreign technology and technical efficiency is negative and lastly, internal R&D in combination with the adoption of foreign technology have a positive effect on technical efficiency. We use cross-sectional firm level survey data from the 2013 World Bank Enterprise Survey and the linked 2014 Innovation Follow-up Survey for examining the effect of innovation activities on firms' technical efficiency. We test our hypothesis using cross-sectional stochastic frontier analysis. We find that internal R&D has a negative and significant effect on technical efficiency. Adoption of foreign technology on the other hand does not have a significant effect on technical efficiency. Nevertheless, the combination of internal R&D and adoption of foreign technology has a negative and significant effect on technical efficiency. We conclude that internal R&D may have dynamic effects on technical efficiency. Furthermore, efficiency may be observed in firms conducting internal R&D but results in relative inefficiency for firms not conducting R&D giving rise to overall inefficiency in the manufacturing industry. Lastly, low rates of human capital hamper R&D activity and the adoption of foreign technology in manufacturing firms in developing countries.

Keywords
Manufacturing firms • internal R&D • adoption of foreign technology • technical efficiency • stochastic frontier analysis

JEL Classification
C21 • D24 • 014 • 030

This research was funded with support from the Department for International Development (DFID) in the framework of the research project 'Enabling Innovation and Productivity Growth in Low Income Countries' (EIP-LIC/PO5639)

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1 Introduction

Innovation is described as a “creative destruction” process that underlies economic development (Schumpeter 1942). The innovation process entails the transformation of innovation inputs such as internal R&D into innovative outcomes including product and process innovations. In addition, the innovation process also encompasses the adoption and imitation of foreign technologies for enhanced productivity and efficiency. Imitation relates to the extent to which a firm invests in imitative research activities in adopting foreign technologies (Geroski 1995; Cameron et al. 2005). Thus, firms may pursue internal R&D and/or adopt foreign technology (Caves and Uekusa 1976; Cohen and Levinthal 1990) as innovation activities aimed at increasing productivity and efficiency in the transformation of factors of production. Technical efficiency, a fundamental measure of economic efficiency, refers to the maximum possible output given a set of inputs (Aigner et al. 1977). Achieving technical efficiency has been thought to produce the highest gains for firms. This is because the fundamental problem of scarcity of resources implies that firms must employ new and more efficient ways of production. Hence, scarcity of resources attaches importance to efficiency since resource constrained firms aim to produce maximal output (Luptáčik 2010) subject to scarce resources.

The manufacturing sector is a significant engine of growth and catch up. This sector is viewed as a source of modernization, skilled job creation and positive spill overs (Tybout 2000). Efficiency in the manufacturing sector in developing countries is critical for industrial development, yet, inefficiency is a distinctive feature of the manufacturing sector in developing countries (Sleuwaegen and Goedhuys 2003). Other distinctive features of the operational environment for manufacturing firms in developing countries include limited access to specialized manufactured inputs, low levels of human capital, poor infrastructure, volatile macroeconomic environment and poor governance (Tybout 2000).

In as much as persistent disparities in various firm level characteristics result in relative differences in efficiency (Bloom and Reenen 2011; Korres 2012), a review of previous studies indicates that there are no empirical studies examining how innovation activities impact technical efficiency in developing countries. Numerous studies focus on firm size and efficiency or on firm size, age and efficiency (Pitt and Lee 1981; Martin and Page 1983; Corbo and de Melo 1986; Chen and Tang 1987; Clerides et al. 1998; Lundvall and Battese 2000; Diaz-Mayans and Sánchez 2008; Niringiye et al. 2010; Diaz-Mayans and Sánchez 2013). Furthermore, while it is widely known that productivity is driven by technical efficiency, it remains unclear to what extent indigenous innovation comprising internal R&D or adoption of foreign technology or the combination of both innovation activities influence efficiency in firms (Fu et al. 2011). Hence, investigating the sources of technical efficiency in manufacturing firms presents a pertinent issue in developing countries.

We argue that firms may seek to increase efficiency by conducting internal R&D or by adoption of foreign technology or by pursuing both innovation activities. Furthermore, innovative firms are likely to be more efficient relative to non-innovative firms since innovation promotes efficiency. Moreover, the effects internal R&D and adoption of foreign technology may have differential effects on efficiency. Comparisons of these innovation activities and their effects on technical efficiency at the firm level in East Africa are non-existent due to unavailability of firm level data on innovation (Hall 2010). Hence, our study makes two contributions. First, we investigate the efficiency effects of internal R&D and adoption of foreign technology as innovation activities by examining whether there are significant differences in how they impact technical efficiency using new firm level data from the 2013 World Bank Enterprise Survey (ES) and the linked 2014 Innovation Follow-up Survey (IFS). In addition to determining the sources of technical efficiency in manufacturing firms in developing countries, such a comparison enables us to identify the innovation activity that most effectively influences technical efficiency in manufacturing firms in developing countries. Second, we examine whether the combination of the two innovation activities significantly enhance technical efficiency.

2 Theoretical background

A technically efficient firm is one in which an increase in an output requires an increase in at least one input or a reduction in at least one other output, and if a decrease in an input has to be accompanied by a reduction in at least one other output or an increase in one other input (Koopmans 1951; Porcelli 2009). Thus, the notion of technical efficiency relates the maximization of output subject to a given set of factors of production. Given the technology used, inefficiency is the difference between the observed output and the maximum output obtainable. The production possibilities frontier (PPF) provides microeconomic foundations of technical efficiency. The PPF defines the maximum potential output that can be achieved by a firm for a given set of inputs and technology. Inefficiency gives rise to deviations from the maximum potential output. Determining efficiency differences between firms entails estimating the production frontier where efficient firms are located, inefficiency of the remaining firms are then derived from obtaining their deviation from the frontier (Gumbau and Maudos 2002).

Efficiency in productivity had been largely ignored because of the inherent difficulties of determining producers' potential and the producers' achievement of that potential. While it is widely known that efficiency measures are essentially success indicators by which producers are evaluated, economic theory had for a long time failed to provide a theoretical framework shedding light on factors influencing efficiency in production (Fried et al. 2008). Nevertheless, several authors examine determinants of efficiency using firm-specific characteristics, external factors, ownership and dynamic disturbances that may arise from the degree of a firm's technological innovation (Caves and Barton 1990; Caves 1992).

Essentially, innovation activities including internal R&D and the adoption of foreign technology impact technical efficiency in several ways. First, conducting internal R&D as an innovation activity may increase the efficiency of existing operations. This may be achieved by reducing costs or minimizing wastage of inputs. Second, internal R&D increases innovation activity that may yield new products and services resulting in increased competitive advantage; however, sustaining competitive advantage involves efforts to produce high levels of output from minimal inputs. Third, the adoption of foreign technology from developed countries may increase efficiency if imported equipment are suited to the socio-economic environment of the developing countries adopting them (Fu et al. 2011).

On the one hand, firm level innovation by means of investing in internal R&D is a risky and costly path-dependent process in comparison to the adoption of foreign technology (Fu et al. 2011). Hence, it is more efficient for firms to acquire foreign technology in developing countries. On the other hand, the adoption of foreign technology is dependent on absorptive capacity (Cohen and

Levinthal 1989). In addition, foreign technology may not be suited to the socio-economic conditions of developing countries (Atkinson and Stiglitz 1969; Basu and Weil 1998; Acemoglu 2002) and also suffers from a lack of capabilities for making optimal use of the embedded technology in foreign technology. Thus, the solution for enhancing efficiency may lie in combining different innovation activities for leveraging innovation capabilities (Fu et al. 2011).

Gumbau and Maudos (2002) in their study examining the determinants of efficiency in the manufacturing industry in Spain, use the ratio of a firm's R&D expenditure to its sales for measuring innovation. The authors find a negative relation between R&D expenditure and efficiency. The authors cite two reasons for the anomalous finding. The first is that R&D expenditure may have dynamic effects so that current expenditure on R&D results in future innovation. The second is that there is a possibility that some firms engage in excessive R&D expenditure relative to their competitors, which does result in innovation, but gives rise to inefficiency in these firms. Notwithstanding, another study investigating the determinants of efficiency by means of a stochastic frontier analysis (SFA) using micro-panel data set for manufacturing firms in Spain demonstrates that innovative firms are more efficient relative to non-innovative firms (Diaz-Mayans and Sánchez 2013).

2.1 Hypotheses

Firms that lie close to the technological frontier face fewer imitation opportunities relative to firms lying farther away from the technological frontier. Thus, firms that are closer to the technological frontier have a higher likelihood of opting for internal R&D whilst those that are farther are more likely to imitate productive technologies (König et al. 2012). Furthermore, firms that are closer to the technological frontier exhibit a higher degree of technical efficiency in comparison to firms lying farther away from the technological frontier. Nevertheless, firms using foreign technology in production may also realize efficiency gains. In addition, a degree of complementarity may exist between internal R&D and foreign technology (Caves and Uekusa 1976; Cassiman and Veugelers 2002; Chang and Robin 2006) because firms may rely on imitative or adaptive research activities in adopting foreign technologies (Geroski 1995; Cameron et al. 2005). Firms may rely on foreign technology due to prohibitive R&D costs; however, indigenous innovation is better suited to socio-economic and technological conditions of a country (Aghion and Howitt 2005). Hence, an integrated approach for leveraging innovation capabilities may result in an optimal combination of the two activities (Fu et al. 2011). We incorporate these ideas in the formulation of three hypotheses in the remainder of this section.

2.1.1 Internal R&D and technical efficiency

Innovation entails the transformation of innovation inputs such as internal R&D into innovation outcomes (Cirera 2015). Previous studies shows that internal R&D is a significantly pursued innovation strategy. Moreover, internal R&D is pivotal in explaining technical efficiency. Firms investing in R&D are more productive and efficient (Kumbhakar et al. 2012). Hence, indigenous innovation activities are crucial for productivity and efficiency because they result in technology that is appropriate to the socio-economic and technological conditions where they are developed. The ratio of R&D spending to output has been found to have a positively significant effect on technical efficiency (Sheu and Yang 2005). In addition, R&D expenditure has a positively significant relation with technical efficiency (Kim 2003). Yet, Gumbau and Maudos (2002) find a negative relation between R&D expenditure and efficiency. Torii (1992) argues that efficiency may increase in the case where a firm invests in internal R&D thus increasing capacity for introducing new products and production processes. On the other hand, rapid technological innovation driven by R&D in a firm results in relative inefficiency in non-innovative firms. Notwithstanding, indigenous technology arising from internal R&D gives rise to technology that domestic firms can absorb easily (Li 2011). Inefficiency in manufacturing firms in Sub-Saharan Africa (SSA) is attributed to low levels of investment in R&D and a lack of organized R&D activity resulting in limited capacity for sophisticated R&D activities. In addition, R&D activity tends to be informal in nature (Biggs 1995). Hence, Investment R&D is expected to increase efficiency in SSA (Bigsten et al. 2010). We therefore hypothesize that:

H1: Internal R&D has a positive effect on technical efficiency in developing countries.

2.1.2 Foreign technology and technical efficiency

The adoption of foreign technology as an innovation strategy for enhancing efficiency presents firms with an alternative to internal R&D. Firms that opt for the adoption of foreign technology do so because of the prohibitive costs involved in investing in R&D (Fu et al. 2011). Moreover, firms lying farther away from the technological frontier face considerable foreign technology opportunities. There is a likelihood that foreign technology results in efficiency gains; however, adoption of foreign technology that is not suited to socio-economic and technological conditions in developing countries may give rise to inefficiency (Basu and Weil 1998; Acemoglu and Zilibotti 2001; Isaksson 2007). Imported technologies are biased towards making optimal use of factors of production in the context of the country in which they are produced, therefore, applying such technologies in a country with significantly different factor endowment is unlikely to promote productivity (Acemoglu and Zilibotti 2001; Acemoglu 2002). In addition, developing countries are characterized by an abundance of semi-skilled and unskilled labor, which make it difficult to learn and apply the embedded technology in foreign technology (Fu et al. 2011). Hence, we formulate our hypothesis as follows:

H2: Adoption of foreign technology has a negative effect on technical efficiency in developing countries.

2.1.3 Internal R&D, foreign technology and efficiency

An important determinant of a country’s success in adopting foreign technology is measured by the degree of “imitative” or “adaptive” research activities (Geroski 1995; Cameron et al. 2005). Previous empirical studies also suggest that internal R&D and foreign technology are complementary innovation activities. This is because there is a likelihood of firms relying on their research capacity for modifying and adopting foreign technologies to meet their specific needs (Caves and Uekusa 1976; Cassiman and Veugelers 2002; Chang and Robin 2006; Cirera 2015). This idea led to the distinction between “creative” and “absorptive” R&D with the former relating to original inventions and the latter being oriented towards adoption of foreign technology (Cohen and Levinthal 1989).Thus, successful adoption of foreign technology relies on the degree of absorptive capacity of local firms. Absorptive capacity relates to the ability of identifying, assimilating and exploiting knowledge from the external environment (Cohen and Levinthal 1989). The degree of absorptive capacity depends on human capital and internal R&D, which are crucial for creating new knowledge and promoting learning (Griffith et al. 2004). Hence, successful adoption of foreign technology is conditional on indigenous innovation efforts comprising internal R&D (Fu et al. 2011). Foreign technology and internal R&D efforts are complementary and relying on only one strategy is not optimal for maximizing benefits in developing countries (Rifkin 1975; Fu and Gong 2011). Therefore, foreign technology does not enhance innovation-oriented efficiency unless coupled with internal R&D (Li 2011). Further, it has been argued that firms may import technology from more advanced countries in Africa so that less technical effort is required for adoptive and imitative activities (Biggs 1995) as conditioned on similarities in the socio-economic and technological environment. This implies that semi-skilled and unskilled labor, which is a distinctive feature of human capital in SSA, may be sufficient for exploiting foreign technology. In addition, few firms in SSA engage in formal R&D activities and consequently exhibit sparse innovation-oriented R&D (Biggs 1995). Hence, internal R&D efforts are likely to be "absorptive" in nature. Thus, we argue that efficiency gains emanating from successful adoption of foreign technology depends on internal R&D. We therefore formulate our hypothesis as follows:

> H3: Internal R&D in combination with the adoption of foreign technology reinforce each other's effects on efficiency in developing countries.

3 Data and methods

3.1 Data

The analysis of this study is based on the cross-sectional firm-level survey data for manufacturing firms in Kenya, Tanzania and Uganda from the 2013 World Bank ES and the linked 2014 IFS. The ES reports on the individual firm characteristics and the business environment of an economy while the IFS reports on innovation at the firm-level. Both the ES and IFS provide firm-level information for the years 2010 through 2012. We merge the two datasets using unique firm identifiers to generate a single dataset for our analysis. We deleted all observations with missing values to obtain a dataset containing 125 manufacturing firms that have complete data on the variables of interest.

3.2 Dependent Variable

The SFA estimates the frontier and inefficiency effects simultaneously. The frontier is estimated using the standard variables comprising output, capital and labor. We use annual sales as a measure of output. The ES provides information on "last complete fiscal year's total sales" which is our measure of output. Capital inputs have been found to account for a larger share of output growth. Hence, capital is a key input for the production process (Nehru and Dhareshwar 1993). The ES reports on fixed assets, which we use as a measure of capital. This variable is measured as the net book value (NBV) of fixed assets which we calculate by adding the NBV of machinery, vehicles and equipment to the NBV of land and buildings. We use the Penn World Table (PWT) purchasing power parity (PPP) exchange rates for deflating output and capital measures in order to determine relative values of currencies for Kenya, Tanzania and Uganda. Labor is measured as the number of full-time workers in a firm for the period reported. The ES provides information on the number of "permanent, full-time workers end of last fiscal year" which we use as our measure for labor.

3.3 Independent Variables

Internal R&D. Internal R&D is an important innovation strategy for firms (Caves and Uekusa 1976; Cohen and Levinthal 1990). The IFS reports on whether firms engage in internal R&D which the study measures as a dummy variable taking a value of “1” if a firm engages in internal R&D and “0” if otherwise.

Foreign technology. Adoption, imitation and adaptation of foreign technology is an important innovation strategy in developing countries since they are likely to lie farther away from the technological frontier (König et al. 2012; Kline and Rosenberg 1986; Bell and Pavitt 1993). Use of foreign technology is reported by the ES which provides information on whether the firm uses technology from foreign companies in production. This is a dummy variable taking a value of “1” if the firm uses technology from foreign companies and “0” if otherwise.

3.4 Control Variables

External financing. External financing describes funds that are obtained outside of the firm. Sources of external financing include banks, non-bank financial institutions, purchasing on credit from supplies and advance payments from creditors. External financing enhances access to innovation inputs such as R&D (Cirera 2015) and purchase of foreign technology External financing may exert pressure on firms to improve efficiency in their operations and production processes to meet stringent lending requirements. In addition, the cost of financing may drive firms to efficiently manage their resources and production processes for profit maximization (Barthwal 2007). The ES reports on the proportion of the firm’s working capital financed from both internal sources (retained earnings) and external sources. External financing is measured using a dummy variable that takes a value of “1” if working capital from external sources exceeds 50 percent.

Access to credit. Access to credit plays a role in increasing efficiency since firms are better placed to increase key innovation inputs such as R&D (Cirera 2015) that may result in efficiency improvements. Financial constraints impede innovation activity (Hall, 2002), therefore, firms with poor access to finance are more likely to be inefficient. Nevertheless, it has been argued that credit constraints increases efficiency in firms arising from effective use of available financial resources and control of costs (Nickell and Nicolitsas 1999). Access to credit is reported in the ES. This variable is measured by a dummy variable that takes a value of “1” if firms have access to credit lines or loans from domestic banks and “0” if otherwise.

Export status. Exporting firms are more efficient than non-exporting firms (Sánchez and Diaz-Mayans 2014). This is in agreement to the argument posed by trade liberalization proponents asserting that exporting enables firms to achieve high levels of efficiency through “learning-by-exporting-effects” (Clerides et al. 1998). Another argument posed for exporters being more efficient is that relatively efficient firms self-select into exporting activity (Clerides et al. 1998). Evidence from manufacturing firms in Kenya shows that exporters are more efficient than non-exporters (Granér and Isaksson 2009). The ES reports on firms’ export status which the study measures using a dummy variable taking a value of “1” if a firm exports and “0” if otherwise.

Human capital. Human capital has been long recognized as a fundamental source of technical progress (Romer 1990). Human capital comprises three elements including early ability, knowledge and qualifications acquired through formal training and skills and experience arising from “on-the-job training”. Highly educated workers are essentially more productive and efficient as they are better able to perform tasks and embrace new production techniques (Blundell et al., 1999). Thus human capital has a positive and statistically significant effect on technical efficiency (Danquah and Quattara 2014). Human capital is measured as the average years of education for a production worker as reported in the ES.

Firm age. This is a firm-specific characteristic whose effects on efficiency are ambiguous. A positive relation is possible due to learning-by-doing arising from cumulative experience in production. Notwithstanding, a negative relation may arise from use of old capital equipment and inefficient production practices (Deraniyagala 2001). The ES provides information on age which is measured as the difference between the year of the survey, 2013 and the year the firm began its operations.

Firm size. The effects of firm size on technical efficiency are ambiguous. A positive effect can be predicted when considering economies of scale and access to finance which enables investing in skills and technologies. On the other hand, a negative effect can be predicted where large firms experience scale diseconomies in production arising from a widening span of control. The existing evidence from East Africa suggests that the link between efficiency and size is not strong in either direction (Niringiye et al. 2010).Notwithstanding, we use this firm specific characteristic as an explanatory variable for the variance in the noise component of the model to account for differences firm size (Belotti et al. 2012). The ES reports on the "number of full-time employees in the last fiscal year" which is our measure of size. Size is a dummy variable taking the value of "1" where a firm has more than 20 employees. The ES categorizes firms with fewer than 20 employees as small and micro enterprises whilst those with more than 20 employees are comprise a continuum of medium to large sized firms.

Country dummies. We control for differences between countries using country dummies that capture external environment and market conditions to account for country specific inefficiency effects. Kenya is the reference category.

3.5 Analysis

There are two competing methods of measuring efficiency including the SFA, a parametric approach and the data envelope analysis (DEA), a non-parametric approach. In an environment characterized by 'noise', the SFA provide better efficiency estimates in comparison to linear DEAs since the SFA takes random disturbances into account (Nanka-Bruce 2004).The SFA, formulated by Aigner et al. (1977) and Meeusen and van den Broeck (1977) is based on estimating the frontier production function arising from the microeconomic premise that firms produce maximum output subject to a set of inputs (Greene 1997). The SFA has three components including the deterministic, production function, the idiosyncratic (noise) error and the inefficiency error. Across-sectional stochastic frontier and inefficiency effects are estimated simultaneously by the method of maximum likelihood (MML) with inefficiency effects being explained by the independent variable and control variables (Kumbhakar and Lovell 2000; Porcelli 2009; Belotti et al. 2012). The model takes on a function relating the maximum obtainable output to a set of inputs such that for a given firm i:

$$y_i = f(x_i,\beta)\exp(v_i)\exp(-u_i) i = 1, 2, \dots, n. \quad (1)$$

where$y_i$is output for observation i, $f(x_i,\beta)$ is the deterministic component of the production function in which $x_i$is the input vector for observation $i$and$\beta$is a vector of parameters, the first error component $\exp(v_i)$ is the stochastic component of the production function accounting for the statistical noise in the production processes and is assumed to be $v_i \sim N(0,\sigma_v^2)$ and the second error component u_i represents technical inefficiency and is assumed to be identically and independently distributed of v_i to satisfy the restriction of $u_i \geq 0$ which follows $v_i \sim N^+(0, \sigma_u^2)$, a half-normal (Aigner et al. 1977) or $u_i \sim \varepsilon(\sigma_u)$, an exponential distribution (Meeusen and van den Broeck 1977). The MML is appropriate for estimating the model due to the distributional assumptions required for the inefficiency term that makes it possible to derive the likelihood function that is maximized with respect to all parameters (β, σ_v^2 and σ_u^2) to obtain consistent estimates of β (see Appendix 1).

The implicit assumption is that the leading firm is itself the frontier and the single benchmark for the rest of the firms. Some firms may produce less than the frontier output due to inefficiencies. Following Kumbhakar et al. (2012) we consider that if the ratio between the maximum and actual output is $\exp(-u_i)$, the inefficiency measure becomes:

$$e_i^{sf} = \exp(-u_i) = \frac{y_i}{f(x_i, \beta)\exp(v_i)} \qquad i = 1, 2, \dots, n. \tag{2}$$

where $e_i^{sf} \in (0, 1]$ and unity values indicate fully efficient firms. A log-linear production function is used for estimating the frontier so that equation (1) becomes:

$$ln\ y_i = ln\ f(x_i, \beta) + v_i - u_i i = 1, 2, \dots, n. \tag{3}$$

where $u_i = log\frac{1}{e_i^{sf}}$ and $f(x_i, \beta)$ can assume a Cobb-Douglas or transcendental logarithmic (translog) functional form. The Cobb Douglas production function is defined as:

$$\ln(Y)_i = \beta_0 + \beta_1 ln(K)_i + \beta_2 ln(L)_i + v_i \quad - u_i \tag{4}$$

The translog production function is defined as:

$$\ln(Y)_i = \beta_0 + \beta_1 ln(K)_i + \beta_2 ln(L)_i + \beta_3 ln(K)_i^2 + \beta_4 ln(L)_i^2 + \beta_5 ln(K)_i ln(L)_i + v_i \quad - u_i \tag{5}$$

where Y_i represents PPP-deflated sales revenue for firm i, K_i represents PPP-deflated NBV of fixed assets for firm i, L_i is the number of full-time workers for firm i while v_i and u_i are random error terms representing the noise and inefficiency component for firm i. The Cobb-Douglas model represents the restricted model and the translog model represents the unrestricted model consisting of cross products and squares of the inputs.

We test for the adequacy of the Cobb-Douglas functional form relative to the less restrictive translog functional form using the generalized likelihood ratio (LR) test. In the selection of the functional form, the null hypothesis is that the Cobb-Douglas provides an adequate representation of the data. The LR test indicates that the Cobb-Douglas production function provides an appropriate functional form for our data since we fail to reject the null hypothesis. Hence, the model we estimate takes the form of equation (4). The Cobb-Douglas production function only permits linearity in the relationship between output and production inputs. In addition, it assumes perfect substitution of factors of production or perfect competition on the factors market.

Another important test based on the LR test is also conducted to determine if inefficiency effects needed to be included in the model. This is done by checking whether the source of inefficiency is the random error or inefficiency effects. The key parameter lying between zero and unity is given as $\gamma = \sigma_u^2 / \sigma_u^2 + \sigma_v^2$ with the null hypothesis stating that $\gamma = 0$ which implies the absence of inefficiency effects that makes the estimation of the stochastic frontier unnecessary because means response function(ordinary least squares) provides an adequate representation of the data (Battese and Coelli 1993). The stochastic frontier approach is appropriate when γ lies close to unity. Our rejection of the null hypothesis indicates that inefficiency effects are present suggesting that an inefficiency effects model is suitable for our analysis.

Following previous studies (Kumbhakar and Lovell 2000; Wang 2002; Kumbhakar et al. 2012), we introduce explanatory variables (z) into equation (4) to explain inefficiency with the assumption that $u_i \sim N^+(0, \sigma_{ui}^2)$ where σ_{ui}^2 is specified as:

$$\sigma_{ui}^2 = \delta_o + \sum_{j=1}^{J} \beta_j z_{j,i} \tag{6}$$

where $j = 1, 2, \ldots, J$ represents the explanatory variables in z including internal R&D/adoption of foreign technology, export status, external financing, access to credit, human capital and firm age. Thus, we consider three inefficiency effects models where the first examines internal R&D and the second examines adoption of foreign technology and the third the interaction of internal RD and adoption of foreign technology:

$$u_i = \sigma_0 + \sigma_1 IternalRD_i + \sigma_2 Export_i + \sigma_3 Extfin_i + \sigma_4 Credit_i + \sigma_5 HC_i + \sigma_6 Age_i \tag{7}$$

$$u_i = \sigma_0 + \sigma_1 Foreigntech_i + \sigma_2 Export_i + \sigma_3 Extfin_i + \sigma_4 Credit_i + \sigma_5 HC_i + \sigma_6 Age_i \tag{8}$$

$$u_i = \sigma_0 + \sigma_1 (InternalRD * Foreigntech_i) + \sigma_2 Export_i + \sigma_3 Extfin_i + \sigma_4 Credit_i + \sigma_5 HC_i + \sigma_6 Age_i \tag{9}$$

where $InternalRD_i$ is the internal R&D for firm i in equation (6), and $Foreigntech_i$ represents the adoption of foreign technology for firm i in equation (7). Equation (8) contains the interaction of internal R&D and the adoption of foreign technology. The remaining variables in (7) , (8) and (9) are the same, $Export_i$ represents the export status for firm i, $Extfin_i$ represents external financing for firm i, $Credit_i$ represents access to credit for firm i, HC_i represents human capital for firm i and Age_i represents the firm age for firm i.

The presence of observable but uncontrolled heterogeneity in u_i and v_i may affect the inference in stochastic frontier models (Kumbhakar and Lovell 2000). Uncontrolled heteroscedasticity leads to biased inefficiency estimates (Belotti et al. 2012). Equation (4), the baseline equation introduced by Aigner et al. (1977) and Meeusen and van den Broeck (1977) has been extended such that the variance in the inefficiency term depends on the independent variables (z) and the noise term is allowed to be heteroscedastic due to variances arising from differences in the size of firms (see Appendix).

4 Results

Table 1 provides descriptive statistics and correlations for the whole sample. Tables 2-6 provide descriptive statistics and correlations for the different categories of firms in the sample. Specifically, Tables 2-5 show descriptive statistics and correlations for firms engaging in internal R&D, firms not engaging in internal R&D, firms adopting foreign technology and firms not adopting foreign technology respectively. Table 6 provides descriptive statistics and correlations for firms pursuing both innovation activities. The average values for firms engaging in internal R&D are on the overall larger than for those not engaging in internal R&D with the exception of average values on adoption of foreign technology and external financing. Moreover, firms engaging in internal R&D report higher average values on most variables than those of the entire sample in comparison to those of firms not engaging in internal R&D. Nevertheless, firms that did not conduct internal R&D had much higher average values than those not adopting foreign technology. Furthermore, average values for firms adopting foreign technology are generally much higher than those of firms not adopting foreign technology. Also, average values on most variables for firms adopting foreign technology are higher than those of the entire sample when compared to firms not adopting foreign technology. The only exception is the average value of internal R&D which is much higher in firms not adopting foreign technology. Average values for firms engaging in both innovation activities are much higher on a majority of variables in comparison to those of firms engaging in only one or none of the innovation activities and the entire sample. Notwithstanding, the average values of external finance are much lower for firms engaging in both innovation activities in comparison to firms conducting R&D and those not conducting R&D. Also, the average values of exporter status for firms engaging in both activities are lower than those of firms adopting foreign technology.

The SFA approach constructs a frontier from efficient firms that envelopes relatively inefficient firms. There are several assumptions made. First, the production function is assumed to be valid for all firms. Second, production technology is the same for all firms, implying that production technology is not heterogeneous. Assumptions are also made about the functional form that the production function takes and the distributional form of the error term. The maximum-likelihood estimates of the SFA and the inefficiency model estimates arising from the estimation of Equation 4 given the specification of the inefficiency effects in Equation 5 are shown in Table 7. Models 1-2 provide the results from our estimation of the baseline equation with internal R&D and foreign technology as the innovation activities respectively. Model 3 provides results for the model with interaction effects of pursuing both internal R&D and foreign technology as innovation activities. Table 8 provides results for models 4-6 that test the robustness of our results in models 1-3 to including foreign ownership and managerial experience as control variables.[2]

Production inputs including capital and labor in the stochastic frontier estimation had positive and statistically significant coefficients in all the models as expected. In addition, firm size was found to have a negative and statistically significant coefficient as an explanatory variable for heteroscedasticity across all the models.

Contrary to our hypothesis that internal R&D has positive effects on technical efficiency in developing countries (H1), we find that internal R&D has a negative and significant relation with technical efficiency. Model 1 shows that internal R&D has a positive and significant effect on technical inefficiency. Control variables including external financing and export status have negative and statistically significant coefficients as expected. Access to credit had a positive and statistically significant effect on technical inefficiency. The human capital coefficient has a negative sign as expected but is not statistically significant. Firm age has a negative but not statistically significant effect on inefficiency. The coefficient of the country dummy comparing Tanzania and Kenya is not statistically significant, however, the coefficient capturing the differences between Uganda and Kenya is positive and statistically significant. Thus, manufacturing firms in Uganda are less efficient than those in Kenya.

Model 2 shows that the relation between adoption of foreign technology and inefficiency is negative but not statistically significant. Hence, we find no support for the second hypothesis (H2) that the adoption foreign technology has a negative relation with technical efficiency in developing countries. The coefficient for external financing is negative and statistically significant; however, the rest of the control variables do not have statistically significant effects on inefficiency.

Model 3 indicates that the coefficient of the interaction effect of the two innovation activities is positive and statistically significant. Our results do not support the third hypothesis (H3) that adoption of foreign technology and internal R&D reinforce each other's effects on technical efficiency in developing countries. On the contrary, the combination of the two innovation activities diminish each other's effects on technical efficiency. Hence, there is a statistically significant difference between firms engaging in both internal R&D and the adoption of foreign technology and those not engaging in any innovation activity with the latter being the reference category. Firms engaging in both innovation activities are inefficient in comparison to those not engaging in any innovation activity. In addition, there is no statistically significant difference between firms engaging in only one of the two innovation activities and those not engaging in any innovation activity. The coefficients for two control variables including external financing and access to credit are statistically significant with external finance positively influencing technical efficiency and access to credit having a negative relation with technical efficiency. The rest of the control variables including export status, human capital and firm age did not have statistically significant effects on inefficiency. The coefficient for the country dummy comparing Tanzania and Kenya is not statistically significant while that comparing Uganda and Kenya is positive and statistically significant implying that manufacturing firms in Uganda are inefficient in comparison to firms in Kenya. Robustness checks results from models 4-6 indicate that the main qualitative conclusions remain unchanged.

[2] Mazaheri and Mazumdar (2005) estimate a trans-log production function to examine determinants of technical inefficiency using Regional Program on Enterprise Development (RPED) survey data collected between 1992 and 1996 in five countries in SSA (Ghana, Kenya Tanzania, Zambia and Zimbabwe). They find that firms with more experienced managers are more technically efficient. In addition, foreign ownership increases technical efficiency.

5 Discussion

Our findings do not support our hypotheses to a large extent. The negative relation between internal R&D and technical efficiency is a surprising finding given the context of the study. Biggs (1995) argues that inefficiency in manufacturing firms in SSA is attributed to low levels of investment in internal R&D and a lack of organized R&D activity. Hence, investing in internal R&D is expected to enhance technical efficiency (Bigsten et al. 2010). Nevertheless, previous empirical studies provide mixed results for the relationship between internal R&D and technical efficiency. Several studies find a positive and significant relationship between internal R&D and technical efficiency (Kim 2003; Sheu and Yang 2005; Kumbhakar et al. 2012; Diaz-Mayans and Sánchez 2013). In contrast our result indicating a negative relation between R&D expenditure and technical efficiency is similar to that of Gumbau and Maudos (2002). There are several plausible explanations for this anomalous result. First, we argue that internal R&D in a firm may lead to efficiency within the firm but results in relative inefficiency in firms not pursuing internal R&D resulting in overall inefficiency (Torii 1992). Secondly, firms engaging in excessive R&D may adopt wasteful practices which in turn result in inefficiency (Gumbau and Maudos 2002) though this is highly unlikely given that few firms engage in formal R&D in Africa (Biggs 1995). Thirdly, internal R&D may have dynamic effects such that current internal R&D may not influence efficiency in the current period but in future time periods (Gumbau and Maudos 2002).

Our results also indicate that the relation between the adoption of foreign technology and technical efficiency is positive but not statistically significant. Thus, the use of technology from foreign countries does not significantly influence technical efficiency in developing countries. Nevertheless, the positive sign of the coefficient of the adoption of foreign technology may be indicate that foreign technology is imported from more advanced countries in Africa such that little technical effort is required for modifying imported equipment (Biggs 1995). Thus, the semi-skilled and unskilled labor that is in abundance in SSA may match the skills required for adoptive and imitative activities in modifying foreign technology imported from Africa. Hence, foreign technology imported from Africa is likely to be more suited to the socio-economic and technological environment of countries in SSA.

The finding that the interaction of internal R&D and adoption of foreign technology negatively impact technical efficiency is unexpected. Previous studies argue that there is a degree of complementarity between internal R&D and the adoption of foreign technology (Caves and Uekusa 1976; Cassiman and Veugelers 2002; Chang and Robin 2006; Fu et al. 2011; Cirera 2015) since successful adoption of foreign technology depends on the degree absorptive capacity of a firm, which in turn depends on human capital and internal R&D (Griffith et al. 2004). Thus, adoption of foreign technology is conditional on internal R&D that is "absorptive" in nature. In addition, it has been argued that engaging in either internal R&D or the adoption of foreign technology does not yield optimal benefits for developing countries (Rifkin 1975; Fu and Gong 2011). Notwithstanding, our findings indicate that engaging in both innovation strategies does not give rise to efficiency gains for manufacturing firms in developing countries. This could be attributed to prohibitive costs of conducting internal R&D (Fu et al. 2011) and low rates of human capital (Tybout 2000) in developing countries implying that few firms engage in formal R&D and lack capacity for sophisticated R&D activities (Biggs 1995). In addition, where technology is imported from developed countries as opposed to more advanced countries in Africa, low rates of skilled labor may hamper the imitative and adaptive activities required for modifying imported equipment (Fu et al. 2011) for production.

The control variable external financing has a positive relation with technical efficiency across all models. This finding offers support for the argument that firms with external financing are more efficient than those without external financing. This result points towards the argument that firms improve their operations and production processes due to borrowing requirements and external pressures from lenders making them more efficient. In addition, the cost of borrowing may push firms to adopt more efficient production practices for profit maximization (Barthwal 2007). On the other hand, access to credit has a negative relation with technical efficiency for firms engaging in internal R&D and in the interaction effects model. Hence, firms may adopt less efficient practices in managing financial resources and costs in an environment with no credit constraints (Nickell and Nicolitsas 1999). We also find that exporting has a positive relation with technical efficiency for firms conducting R&D (Clerides et al. 1998; Granér and Isaksson 2009; Sánchez and Diaz-Mayans 2014). This result suggests that export promotion policies promoting export participation for firms engaging in internal R&D play a significant role in improving technical efficiency in developing countries.

5.1 Policy implications

Our results suggest that conducting internal R&D in manufacturing firms in developing countries results in inefficiency. Hence, firms conducting internal R&D are inefficient relative to those not conducting internal R&D. Our interpretation of this finding is that there is a high likelihood that few firms engage in formal R&D activities, which results in inefficiency in the entire manufacturing industry. Furthermore, internal R&D in one firm or a subset of firms may result in relative inefficiency for firms not conducting internal R&D in the context of developing countries. In light of this, it is important that policy makers focus on fostering formal R&D in the manufacturing industry and promoting internal R&D practices that improve efficiency on a large scale for the benefit of more firms. In addition, enhancing external financing for firms is likely to foster efficiency. Hence, policies diversifying external financing instruments are imperative in enhancing efficiency in firms. Another important finding is that exporting firms are closer to the frontier indicating higher levels of efficiency. Therefore, export-oriented policies aimed at increasing export participation in developing countries are essential for increasing efficiency via learning-by-exporting effects.

Another important finding relates to the negatively significant effect of the interacted term (internal R&D*foreign technology) on technical efficiency. This result indicates that pursuing both innovation activities in developing countries is not conducive to improving efficiency in manufacturing firms in developing countries. Adoption of foreign technology may not be suited to production in developing countries, yet if internal R&D is absorptive in nature, such technology may be adapted or modified to suit the specific needs of firms in developing countries resulting in increased efficiency. Therefore, policies fostering the development of human capital targeting "absorptive" R&D may be crucial for efficiency gains in manufacturing firms in developing countries.

Further studies based on larger sample sizes with more comprehensive data may prove useful in substantiating our findings. In addition, further avenues for research depend on the availability of panel data which would enable extensive investigation of the causal effect of innovation activities on technical efficiency, allowing more conclusive interpretation of findings.

Table 1 Descriptive statistics and correlation matrix for the whole sample (n=125)

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10
1	Output (ln)	14.37	2.82	8.11	20.93	–									
2	Capital (ln)	13.66	2.78	7.44	24.25	0.61	–								
3	Labor (ln)	3.57	1.66	0.00	8.29	0.71	0.71	–							
4	Internal R&D	1.66	0.47	1.00	2.00	-0.10	-0.34	-0.23	–						
5	Foreign technology	1.71	0.45	1.00	2.00	-0.23	-0.24	-0.29	0.11	–					
6	External finance	0.52	0.50	0.00	1.00	0.10	0.11	-0.08	-0.04	0.03	–				
7	Access to credit	1.52	0.50	1.00	2.00	-0.01	0.00	-0.11	-0.11	0.10	-0.35	–			
8	Exporter status	0.54	0.50	0.00	1.00	0.25	0.21	0.26	-0.01	-0.16	0.08	-0.08	–		
9	Human capital	11.86	3.88	1.00	21.00	0.14	0.13	0.19	-0.16	-0.21	-0.02	-0.08	-0.02	–	
10	Age (ln)	3.04	0.80	0.69	4.53	0.23	0.30	0.34	-0.10	0.01	0.08	-0.08	0.28	0.25	–
11	Size	0.57	0.50	0.00	1.00	0.53	0.60	0.80	-0.21	-0.27	-0.09	-0.19	0.30	0.14	0.20

Table 2 Descriptive statistics and correlation matrix for firms conducting internal R&D (n=42)

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9
1	Output (ln)	14.75	2.52	10.12	19.91	–								
2	Capital (ln)	14.97	2.83	8.43	24.25	0.60	–							
3	Labor (ln)	4.10	1.57	1.10	8.29	0.77	0.75	–						
4	Foreign technology	1.64	0.48	1.00	2.00	-0.21	-0.23	-0.34	–					
5	External finance	0.55	0.50	0.00	1.00	0.16	0.15	-0.04	0.12	–				
6	Access to credit	1.60	0.50	1.00	2.00	0.05	-0.08	-0.06	-0.01	-0.46	–			
7	Exporter status	0.55	0.50	0.00	1.00	0.22	0.17	0.24	-0.08	-0.15	0.03	–		
8	Human capital	12.71	3.39	2.00	20.00	0.16	-0.15	0.10	-0.24	-0.13	-0.03	0.04	–	
9	Age (ln)	3.14	0.79	1.39	4.53	0.27	0.13	0.27	0.02	0.05	-0.13	0.37	0.26	–
10	Size	0.71	0.46	0.00	1.00	0.50	0.63	0.78	-0.36	-0.15	-0.09	0.27	-0.12	0.10

Table 3 Descriptive statistics and correlation matrix for firms not conducting internal R&D (n=83)

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9
1	Output (ln)	14.18	2.96	8.11	20.93	1.00								
2	Capital (ln)	13.00	2.53	7.44	19.29	0.63	1.00							
3	Labor (ln)	3.31	1.64	0.00	8.29	0.68	0.67	1.00						
4	Foreign technology	1.75	0.44	1.00	2.00	-0.23	-0.21	-0.24	1.00					
5	External finance	0.51	0.50	0.00	1.00	0.07	0.08	-0.11	-0.02	1.00				
6	Access to credit	1.48	0.50	1.00	2.00	-0.05	-0.02	-0.17	0.17	-0.30	1.00			
7	Exporter status	0.54	0.50	0.00	1.00	0.26	0.25	0.28	-0.20	0.20	-0.13	1.00		
8	Human capital	11.43	4.06	1.00	21.00	0.11	0.19	0.19	-0.17	0.02	-0.13	-0.05	1.00	
9	Age (ln)	2.98	0.80	0.69	4.53	0.20	0.38	0.35	0.02	0.09	-0.07	0.24	0.24	1.00
10	Size	0.49	0.50	0.00	1.00	0.54	0.55	0.79	-0.20	-0.08	-0.28	0.33	0.20	0.22

Table 4 Descriptive statistics and correlation matrix for firms using foreign technology (n=36)

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9
1	Output (ln)	15.39	3.03	8.11	20.93	–								
2	Capital (ln)	14.69	3.41	7.44	24.25	0.66	–							
3	Labor (ln)	4.33	1.82	0.00	8.29	0.80	0.72	–						
4	Internal R&D	1.58	0.50	1.00	2.00	-0.02	-0.28	-0.23	–					
5	External finance	0.50	0.51	0.00	1.00	0.18	0.23	0.18	0.06	–				
6	Access to credit	1.44	0.50	1.00	2.00	-0.01	-0.07	-0.02	-0.26	-0.67	–			
7	Exporter status	0.67	0.48	0.00	1.00	0.24	0.19	0.19	0.12	0.00	0.04	–		
8	Human capital	13.11	3.61	2.00	21.00	0.20	0.27	0.22	-0.16	0.12	0.08	-0.47	–	
9	Age (ln)	3.02	0.82	1.39	4.53	0.41	0.37	0.50	-0.10	0.26	-0.14	0.21	0.27	–
10	Size	0.78	0.42	0.00	1.00	0.53	0.56	0.70	-0.32	0.13	-0.06	0.05	0.05	0.23

Table 5 Descriptive statistics and correlation matrix for firms not using foreign technology (n=89)

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9
1	Output (ln)	13.96	2.64	8.14	20.32	–								
2	Capital (ln)	13.25	2.39	7.78	19.21	0.54	–							
3	Labor (ln)	3.27	1.49	0.69	7.70	0.63	0.68	–						
4	Internal R&D	1.70	0.46	1.00	2.00	-0.10	-0.35	-0.19	–					
5	External finance	0.53	0.50	0.00	1.00	0.07	0.06	-0.20	-0.09	–				
6	Access to credit	1.55	0.50	1.00	2.00	0.03	0.07	-0.11	-0.06	-0.22	–			
7	Exporter status	0.49	0.50	0.00	1.00	0.22	0.18	0.25	-0.03	0.12	-0.10	–		
8	Human capital	11.36	3.90	1.00	21.00	0.05	-0.01	0.11	-0.13	-0.06	-0.11	0.09	–	
9	Age (ln)	3.04	0.79	0.69	4.53	0.16	0.29	0.29	-0.09	0.00	-0.05	0.32	0.26	–
10	Size	0.48	0.50	0.00	1.00	0.50	0.61	0.83	-0.14	-0.17	-0.21	0.35	0.11	0.20

Table 6 Descriptive statistics and correlation matrix for firms combining internal R&D and foreign technology (n=15)

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8
1	Output (ln)	15.45	2.90	10.12	19.91	–							
2	Capital (ln)	15.82	3.46	9.10	24.25	0.50	–						
3	Labor (ln)	4.81	1.64	1.61	8.29	0.80	0.67	–					
4	External finance	0.47	0.52	0.00	1.00	0.31	0.46	0.37	–				
5	Access to credit	1.60	0.51	1.00	2.00	-0.12	-0.47	-0.20	-0.87	–			
6	Exporter status	0.60	0.51	0.00	1.00	0.22	0.29	0.30	-0.05	0.17	–		
7	Human capital	13.80	2.62	10.00	20.00	0.50	0.24	0.40	0.18	-0.12	-0.39	–	
8	Age (ln)	3.12	0.93	1.39	4.53	0.48	0.33	0.67	0.04	-0.08	0.31	0.25	–
9	Size	0.93	0.26	0.00	1.00	0.24	0.54	0.54	0.25	-0.22	0.33	-0.13	0.52

Table 7 Maximum-Likelihood estimates of the SFA (n=125)

Variables	**Model 1**		**Model 2**		**Model 3**	
Stochastic frontier estimates						
Capital (ln)	0.261***	(0.096)	0.208**	(0.100)	0.288***	(0.095)
Labor (ln)	0.925***	(0.152)	0.996***	(0.162)	0.939***	(0.146)
Constant	8.192***	(1.020)	8.499***	(1.179)	7.834***	(1.017)
Inefficiency effects						
Internal R&D	2.499**	(1.134)				
Foreign technology			-0.338	(1.179)		
Internal R&D*Foreign technology(0/1)					-2.263	(1.890)
Internal R&D*Foreign technology(1/0)					1.608	(1.053)
Internal R&D*Foreign technology(1/1)					2.049*	(1.166)
External finance	-2.693**	(1.241)	-2.029*	(1.184)	-1.774*	(0.986)
Access to credit	1.665*	(0.971)	0.763	(1.347)	1.619*	(0.844)
Exporter status	-1.856*	(1.021)	-1.015	(1.225)	-1.241	(0.877)
Human capital	-0.100	(0.098)	-0.129	(0.180)	-0.108	(0.0951)
Firm age (ln)	0.557	(0.527)	1.024	(1.501)	0.407	(0.465)
Tanzania	-0.654	(2.622)	-2.100	(7.109)	-1.050	(2.377)
Uganda	2.096**	(0.969)	2.253	(1.855)	1.924**	(0.877)
Constant	-1.715	(1.962)	-2.303	(3.899)	-0.826	(1.802)
Heteroscedasticity						
Firm size	-0.601**	(0.292)	-0.559*	(0.299)	-0.663**	(0.286)
Constant	1.329***	(0.198)	1.405***	(0.204)	1.215***	(0.192)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 8 Robustness checks using managerial experience and foreign ownership of firms (n=125)

Variables	**Model 4**		**Model 5**		**Model 6**	
Stochastic frontier estimates						
Capital (ln)	0.221**	(0.0980)	0.220**	(0.0952)	0.266***	(0.0984)
Labor (ln)	1.002***	(0.148)	0.949***	(0.161)	0.958***	(0.147)
Constant	8.385***	(1.056)	8.622***	(1.157)	8.010***	(1.047)
Inefficiency effects						
Internal R&D	2.499**	(1.195)				
Foreign technology			-0.377	(1.164)		
Internal R&D*Foreign technology(0/1)					-2.456	(2.111)
Internal R&D*Foreign technology(1/0)					1.491	(1.084)
Internal R&D*Foreign technology(1/1)					1.977	(1.230)
External finance	-2.766**	(1.345)	-1.987*	(1.136)	-1.871*	(0.984)
Access to credit	1.655	(1.127)	0.0797	(1.682)	1.456*	(0.851)
Exporter status	-1.454	(1.078)	-0.976	(1.211)	-1.170	(0.896)
Human capital	-0.136	(0.130)	-0.212	(0.289)	-0.0904	(0.0981)
Firm age (ln)	0.616	(0.698)	1.249	(2.028)	0.341	(0.470)
Managerial experience	-0.574	(1.108)	-0.190	(1.750)	-0.0887	(0.978)
Foreign ownership	-1.596	(2.559)	-2.769	(2.619)	-0.709	(1.298)
Tanzania	-1.044	(4.216)	-2.178	(5.987)	-1.095	(2.417)
Uganda	2.033**	(0.994)	2.527	(2.325)	1.898**	(0.880)
Constant	-1.208	(2.137)	-1.109	(3.402)	-0.650	(1.928)
Heteroscedasticity						
Firm size	-0.770**	(0.302)	-0.396	(0.287)	-0.579**	(0.283)
Constant	1.404***	(0.204)	1.278***	(0.197)	1.170***	(0.189)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

References

Acemoglu D (2002) Directed technical change. Review of Economic Studies 69:781-809

Acemoglu D, Zilibotti, F (2001) Productivity differences. Quarterly Journal of Economics 116:563-606

Aghion P, Howitt P (2005) Growth with quality-improving innovations: an integrated framework. Handbook of Economic Growth 1:67-110

Aigner D, Lovell CAK, Schmidt P (1977) Formulation and estimation of stochastic frontier production function models. Journal of Econometrics 6:21-37

Atkinson AB, Stiglitz JE (1969) A new view of technological change. The Economic Journal 79:573-578

Barthwal RR (2007) Industrial Economics: an introductory text book. New Age International, New Delhi

Battese GE, Coelli TJ (1988) Prediction of firm-level technical efficiencies with a generalized frontier production function and panel data. Journal of Econometrics 38:87-399

Battese GE, Coelli TJ (1993) A stochastic frontier production function incorporating a model for technical inefficiency effects, Working Papers in Econometrics and Applied Statistics, No. 69, Department of Econometrics, University of New England, Armidale

Battese GE, Coelli TJ (1995) A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Economics 20:325-332

Basu S, Weil DN (1998) Appropriate technology and growth. Quarterly Journal of Economics 113:1025-1054

Bell M, Pavitt K (1993) Technological accumulation and industrial growth: contrasts between developed and developing countries. Industrial Corporate Change 2:157-210

Belotti F, Daidone S, Ilardi G, Atella V (2012) Stochastic frontier analysis using Stata, Centre for Economic and International Series Research Paper Series No. 251

Biggs T (1995) Training, technology and firm-level efficiency in Sub-Saharan Africa, RPED Discussion Paper No. 48

Bigsten A, Kimuyu P, Söderbom M (2010) African firms in the global economy. Review of Market Integration 2:229-253

Bloom N, Van Reenen J (2011) Human resource management and productivity. Handbook of Labor Economics 4:1697-1767

Blundell R, Dearden L, Meghir C, Sianesi B (1999) Human capital investment: the returns from education and training to the individual, the firm and the economy. Fiscal Studies 20:1-23

Cameron G, Proudman J, Redding S (2005) Technological convergence, R&D, trade and productivity growth. European Economic Review 49:775-807

Cassiman B, Veugelers R (2002) Complementarity in the innovation strategy: internal R&D, external technology acquisition and cooperation, Center for Economic Policy Research Discussion Paper No. 3284

Caudill SB, Ford JM (1993). Biases in frontier estimation due to heteroscedasticity. Economics Letters, 41:17-20

Caves RE (1992) Determinants of technical efficiency in Australia. In: Caves R (ed) Industrial efficiency in six nations, MIT Press, Cambridge, MA, pp 241-272

Caves RE, Barton DR (1990) Efficiency in US manufacturing industries. MIT Press, Cambridge, MA

Caves RE, Uekusa M (1976) Industrial organization in Japan. Brookings Institution, Washington, DC

Chang C, Robin S (2006) Doing R&D and/or importing technologies: the critical importance of firm size in Taiwan’s manufacturing industries. Review of Industrial Organization 29: 253-278

Chen TJ, Tang DP (1987) Comparing technical efficiency between import-substitution oriented and export-oriented foreign firms in a developing economy. Journal of Development Economics 26:277-289

Cirera X (2015) Catching up to the technological frontier? Understanding firm-level innovation and productivity in Kenya. World Bank Group. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2015/03/10/000470435_20150310064307/Rendered/PDF/946710REVISED000innovation0in0Kenya.pdf. Accessed 2 April 2015

Clerides SK, Lach S, Tybout JR (1998) Is learning by exporting important? Micro dynamic evidence from Colombia, Mexico, and Morocco. Quarterly Journal of Economics 454:903-947

Cohen WM, Levinthal DA (1989) Innovation and learning: the two faces of R & D. Economic Journal 99:569-596

Cohen WM, Levinthal DA (1990) Absorptive capacity: a new perspective on learning and innovation. Administrative Science Quarterly 35:128-152

Corbo V, De Melo J (1986) Measuring technical efficiency: A comparison of alternative methodologies with census data. Springer, Netherlands

Danquah M, Ouattara B (2014) Productivity growth, human capital and distance to frontier in Sub-Saharan Africa. Journal of Economic Development 39:27-48

Deraniyagala S (2001) The impact of technology accumulation on technical efficiency: an analysis of the Sri Lankan clothing and agricultural machinery industries. Oxford Development Studies 29:101-114

Diaz-Mayans MA, Sánchez-Perez R (2008) Firm size and productivity in Spain: a stochastic frontier analysis. Small Business Economics 30:315-323

Diaz-Mayans MA, Sánchez-Perez R (2013) Are large innovative firms more efficient? Theoretical and Practical Research in Economic Fields 1:89-96

Diaz-Mayans MA, Sánchez R (2014) Innovation, exports and technical efficiency in Spain, MPRA Paper No. 53230

Fried HO, Lovell CAK, Schmidt SS (2008) The measurement of productive efficiency and productivity growth. Oxford University Press, New York

Fu X, Gong Y (2011) Indigenous and foreign innovation efforts and drivers of technological upgrading: evidence from China. World Development 39:1213-1225

Fu X, Pietrobelli C, Soete L (2011) The role of foreign technology and indigenous innovation in the emerging economies: technological change and catching-up. World Development, 39:1204-1212

Geroski PA (1995) Innovation and competitive advantage, OECD Economics Department Working Papers No. 159, OECD Publishing, Paris

Granér M, Isaksson A (2009) Firm efficiency and the destination of exports: evidence from Kenyan plant-level data. Developing Economies 47:279-306

Greene WH (1997) Frontier production functions. Handbook of Applied Econometrics 2:81-166

Griffith R, Redding S, Van Reenen J (2004) Mapping the two faces of R&D: productivity growth in a panel of OECD industries. Review of Economics and Statistics 86:883-895

Gumbau-Albert M, Maudos J (2002) The determinants of efficiency: the case of the Spanish industry. Applied Economics 34:1941-1948

Hadri K (1999) Estimation of a doubly heteroscedastic stochastic frontier cost function. Journal of Business and Economic Statistics 17:359-363

Hall BH (2002) The financing of research and development. Oxford Review of Economic Policy 18:35-51

Hall BH (2011) Innovation and productivity, NBER Working Paper No. 17178, National Bureau of Economic Research, Cambridge

Huang CJ, Liu JT (1994) Estimation of a non-neutral stochastic frontier production function. Journal of Productivity Analysis 5:171-180

Isaksson A (2007) Determinants of total factor productivity: a literature review, United Nations Industrial Development Organization Research and Statistics Branch Staff Working Paper No. 05/2007

Jondrow J, Lovell CAK, Materov IS, Schmidt P (1982) On the estimation of technical inefficiency in the stochastic frontier production function model. Journal of Econometrics 19:233-238

Kim S (2003) Identifying and estimating sources of technical inefficiency in Korean manufacturing industries. Contemporary Economic Policy 21:132-144

Kline SJ, Rosenberg N (1986) An overview of innovation. In: Landau R, Rosenberg N (eds) The positive sum strategy: harnessing technology for economic growth, National Academy Press, Washington, DC, pp 275-304

König M, Lorenz J, Zilibotti F (2012) Innovation vs foreign technology and the evolution of productivity distributions, Stanford Institute for Economic Policy Research Discussion Paper No. 11-008

Koopmans TC (1951) Efficient allocation of resources. Econometrica 19:455-465

Korres MGM (2012) Technical change and economic growth: inside the knowledge based economy. Ashgate Publishing Ltd., Surrey
Kumbhakar SC, Ghosh S, McGuckin, JT (1991) A generalized production frontier approach for estimating determinants of inefficiency in US dairy farms. Journal of Business and Economic Statistics 9:279-286
Kumbhakar SC, Lovell CAK (2000) Stochastic frontier analysis. Cambridge University Press, Cambridge
Kumbhakar SC, Ortega-Argilés R, Potters L, Vivarelli M, Voigt P (2012) Corporate R&D and firm efficiency: evidence from Europe's top R&D investors. Journal of Productivity Analysis 37:125-140
Li X (2011) Sources of external technology, absorptive capacity, and innovation capability in Chinese state-owned high-tech enterprises. World Development 39:1240-1248
Lundvall K, Battese GE (2000) Firm size, age and efficiency: evidence from Kenyan manufacturing firms. Journal of Development Studies 36:146-163
Luptáčik M (2010) Mathematical optimization and economic analysis. Springer, New York
Martin JP, Page JM (1983) The impact of subsidies on X-efficiency in LDC industry: theory and an empirical test. Review of Economics and Statistics 65:608-617
Mazaheri A, Mazumdar D (2005) The African manufacturing firm: an analysis based on firm studies in Sub Saharan Africa. Routledge, London
Meeusen W, van den Broeck J (1977) Efficiency estimation from Cobb-Douglas production functions with composed error. International Economic Review 18:435-444
Nehru V, Dhareshwar A (1993) A new database on physical capital stock: sources, methodology and results. Revista de Análisiseconómico 8:37-59
Nickell S, Nicolitsas D (1999) How does financial pressure affect firms? European Economic Review 43:1435-1456
Niringiye A, Luvanda E, Shitundu J (2010) Firm size and technical efficiency in East African manufacturing firms. Current Research Journal of Economic Theory 2:69-75
Pitt MM, Lee LF (1981) The measurement and sources of technical inefficiency in the Indonesian weaving industry. Journal of Development Economics 9:43-64
Porcelli F (2009) Measurement of technical efficiency. A brief survey on parametric and non-parametric techniques. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.232.4843&rep=rep1&type=pdf. Accessed 29 June 2015
Rifkin SB (1975) The Chinese model for science and technology: its relevance for other developing countries. Development and Change 6:23-40
Romer P (1990) Endogenous technical change. Journal of Political Economy 98:S71–S102
Schumpeter JA (1942) Capitalism, socialism and democracy. Harper, New York
Sheu HJ, Yang CY (2005) Insider ownership and firm performance in Taiwan's electronics industry: a technical efficiency perspective. Managerial and Decision Economics 26: 307-318
Sleuwaegen L, Goedhuys M (2003) Technical efficiency, market share and profitability of manufacturing firms in Côte d'Ivoire: the technology trap. Cambridge Journal of Economics 27:851-866
Torii A (1992) Dual structure and differences of efficiency between Japanese large and small enterprises. In: Caves R (ed) Industrial efficiency in six nations, MIT Press, Cambridge, MA, pp 385-424
Tybout JR (2000) Manufacturing firms in developing countries: how well do they do, and why? Journal of Economic Literature 38:11-44
Wang HJ (2002) Heteroscedasticity and non-monotonic efficiency effects of a stochastic frontier model. Journal of Productivity Analysis 18:241-253

Appendix

For cross section models, we consider the following stochastic frontier model from Belotti et al. (2012):

$$y_i = \alpha + x_i'\beta + \varepsilon_i \qquad i = 1, 2, \ldots, N. \tag{A-1}$$

$$\varepsilon_i = v_i + u_i \tag{A-2}$$

$$v_i \sim N(0, \sigma_v^2) \tag{A-3}$$

$$u_i \sim \mathcal{F} \tag{A-4}$$

where y_i is the logarithm of output of the i-th firm, x_i is a vector of inputs and β represents the vector of technology parameters. The composite error term ε_i consists of v_i, the measurement and specification error and u_i, a one sided disturbance term representing inefficiency. The terms v_i and u_i are assumed to be independently distributed from each other and are independent and identically distributed across observations. In order to estimate the model, an assumption has to be made about the distribution $\mathcal{F}$ of the inefficiency term which can follow $v_i \sim N^+(0, \sigma_u^2)$, a half-normal distribution (Aigner et al. 1977) or $u_i \sim \varepsilon(\sigma_u)$, an exponential distribution (Meeusen and van den Broeck 1977). The distributional assumptions make the model amenable to estimation by means of ML.

SFA is based on two sequential steps. The first involves estimating the model parameters $\hat{\theta}$ by maximizing the log-likelihood function $\ell(\theta)$ where $\theta = (\alpha, \beta', \sigma_u^2, \sigma_v^2)'$. The second step involves obtaining point estimates of the inefficiency term using the mean or mode of the conditional distribution $f(u_i \mid \hat{\varepsilon}_i)$, where $\hat{\varepsilon} = y_i - \hat{\alpha} - x_i'\hat{\beta}$. The basis of the derivation of the likelihood function is the assumption of the independence of u_i and v_i . It follows that with the composite error term being defined as $\varepsilon_i = v_i + u_i$ its probability density function is then the convolution of the two error component densities given as:

$$f_\varepsilon(\varepsilon_i) = \int_0^{+\infty} f_u(u_i) f_v(\varepsilon_i + v_i)\, du_i \tag{A-5}$$

Thus, for a sample of n firms, the log-likelihood function is given as:

$$\ell(\theta) = \sum_{i=1}^{n} \log f_\varepsilon(\varepsilon_i \mid \theta) \tag{A-6}$$

The second estimation step allows for the computation of residuals $\hat{\varepsilon}$ but does not allow for the computation of inefficiency estimates, hence, activities for disentangling the separate contributions of v_i and u_i to the residual derive the conditional distribution of u given ε (Jondrow et al. 1982; Battese and Coelli 1988). Therefore, using the mean $\mathbb{E}(u \mid \hat{\varepsilon})$ or mode $\mathbb{M}(u \mid \hat{\varepsilon})$of the conditional distribution, Battese and Coelli (1995)obtain a point estimate of $u$from which the estimates of technical efficiency are derived as:

$$\text{Technical efficiency} = \exp(-\hat{u})$$

where $\hat{u}$ is either $\mathbb{E}(u \mid \hat{\varepsilon})$ or $\mathbb{M}(u \mid \hat{\varepsilon})$.

The model that allows for heteroscedasticity is obtained by scaling the distribution of the inefficiency term. There are two alternative have been proposed, the first involves introducing exogenous variables in the inefficiency effects model in the location of the distribution. This is done by parameterizing the mean of the pre-truncated inefficiency distribution (Kumbhakar et al. 1991; Huang and Liu 1994) were models (1) to (3) are completed with:

$$u_i \sim N^+(\mu_i, \sigma_u^2) \tag{A-7}$$

$$\mu_i = z_i'\psi \tag{A-8}$$

where u_i is a realization form a truncated normal random variable, z_i is a vector of exogenous variables including the constant term and ψ is a vector of the inefficiency effects. The second alternative proposed by Caudill and Ford (1993), Caudill et al. (1995) and Hadri (1999) involves parameterizing the variance of the pre-truncated inefficiency distribution as follows:

$$u_i \sim N^+(0, \sigma_{ui}^2)$$

(A-9)

$$\sigma_{ui}^2 = \exp\,(z_i'\psi)$$

(A-10)

This last specification is extended by Hadri (1999) to allow the variance in the idiosyncratic(noise)error component to be heteroscedastic such that model (3) becomes:

$$v_i \sim N(0, \sigma_{vi}^2)$$

(A-11)

$$\sigma_{vi}^2 = \exp\,(h_i'\phi)$$

(A-12)

where the variables in $h_i$do not necessarily have to appear in z_i.